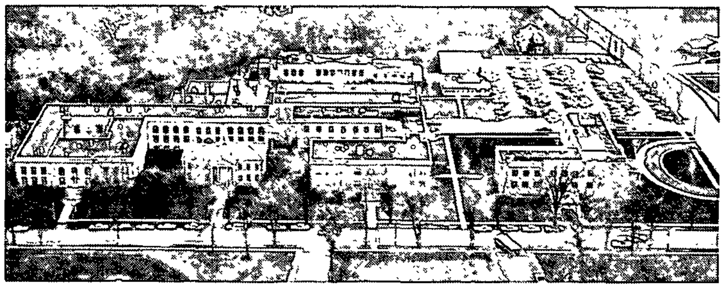

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IMPULSE DRYING: A STATUS REVIEW

Clyde H. Sprague* and Hugh P. Lavery**

ABSTRACT

Impulse drying is an important new web consolidation process with the potential to replace a large part of both the pressing and drying sections of a paper machine. As such, impulse drying offers savings in capital and energy costs, improvements in paper properties, reductions in raw material costs and other benefits. Under the sponsorship of the U.S. Department of Energy and with the support of its member companies, The Institute of Paper Chemistry is vigorously pursuing the development of impulse drying. The specific objective is the development of the database necessary for the quick, effective commercial implementation of the process.

This paper will provide a review of new results in the continuing development of impulse drying, integrated with a background review on the process. New results include drying of sheets from initial solids levels typical of those in the wet pressing section, energy efficiency of the impulse drying process alone and combined with finish drying in a conventional cylinder dryer, the development of a laboratory scale pilot impulse dryer and results therefrom, the fundamentals of bonding and strength development in sheets made from high-yield furnishes, felt and engineering issues, and other recent data. Special attention will be given to liner, newsprint, and high-yield furnishes.

INTRODUCTION

In papermaking, water is removed first by simple drainage elements and then by pressing and drying. These processes, along with the furnishes used with them, have evolved together over the years. They now perform about as well as fundamental limitations allow. Nevertheless, there is an urgent need for better methods. Current processes are slow, energy intensive, capital intensive, limited in their ability to develop or control paper properties, and fall far short of developing the full potential of available fiber sources. For these reasons, there is a strong world-wide

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effort to improve web consolidation, much of it through development of new processes.

In the quest for better performance, several so-called high-intensity web consolidation processes have evolved (1-4). Most involve some form of combined pressing and drying. Press drying (2) is based on the notion that the sheet must be fully restrained until dry and that the flow of lignin and hemicellulose is critical to product properties. In contrast, when Wahren initiated his work on impulse drying (4) more than ten years after the first press drying work (1), rapid dewatering was the primary target. Little early attention was paid to property development. Subsequent development work on impulse drying (5) has operated within the range of currently achievable pressing parameters in hopes of facilitating commercial implementation. Typically, pressures range from 1.0-5.0 MPa, surface temperatures from 150-500°C, and nip residence times from 15 to 100 ms. These conditions provide full restraint of the sheet, but only until it is partially dried. A few cylinder dryers following the impulse dryer will be needed to finish drying the sheet.

EXPERIMENTAL TECHNIQUES

To simulate impulse drying on the bench scale, a heated platen press is driven by a Materials Testing Systems (MTS) electrohydraulic servo which provides the pressure and time conditions representative of a press nip. A presteaming ring can be used to raise sheet temperatures to near 90°C before impulse drying. Handsheets are impulse dried under various conditions and then finish-dried on a conventional drying simulator. A few sheets are dried completely on this simulator to provide a control.

Total water removal is measured gravimetrically. Liquid water removal is measured with a lithium chloride tracer technique (6). The amount of water vapor formed is calculated as the difference between total and liquid water removal. The heat requirement is calculated from a simple energy balance.

The time history of the heat supplied is obtained from a junction thermocouple in the hot surface and a heat transfer model (7). Fine-gage thermocouples (0.025 mm diameter) in layered sheets are used for temperature measurement. The z-direction compressive profile history of the sheet is measured dynamically with a technique developed by Burton (8).

MECHANISMS

Wet pressing removes water principally by volume reduction through sheet compression which induces a hydraulic pressure gradient (9-10). Impulse drying adds hot roll surface temperature to this familiar process. This has a dramatic new effect on dewatering and densification. For example, impulse drying is much less dependent on sheet initial moisture content, yields much higher levels of dewatering at all ingoing moistures, even down to 15%, and continues to be effective at 70-80% initial solids, well beyond the wet pressing range, (Fig. 1). These data, and many others, strongly suggest that the brief exposure to intense conditions in impulse drying invokes dewatering and densifying mechanisms not exhibited by any conventional processes. Some of these were recognized by Gottwald, et al. (1) in their pioneering work on a form of press drying. Several other authors (6,11-13) identified all of these new mechanisms.

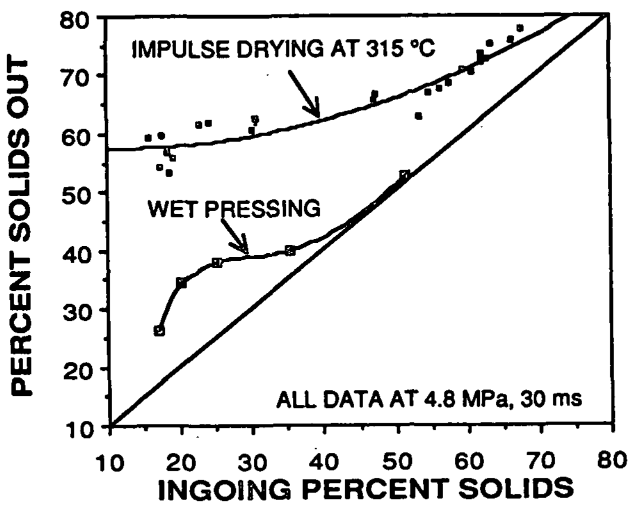

Figure 1. Comparative water removal performance for impulse drying and wet pressing of 127 g/m^2 linerboard pre-heated to 82°C.

The most important of these new mechanisms is the early generation of a vapor-filled zone next to the hot surface and an abutting liquid-filled zone next to the felt. Liquid is displaced into the felt as the vapor zone grows. A large amount of water is removed as liquid by this mechanism, leading to extremely rapid dewatering and excellent energy efficiency. This mechanism alone accounts for much of the difference between impulse drying and wet pressing.

In addition, a heat pipe type of heat transfer process causes rapid heating through the vapor zone next to the hot surface. This causes thermal softening and the flow of lignin and hemicellulose, much as reported for the much longer press drying processes (14). This portion of the fiber network is dried and cooled by flash evaporation as the applied pressure is reduced at the nip exit. It becomes extremely well bonded and dense, leading to excellent surface properties on the finished sheet.

Initially, an impulse dryer was expected to follow a good press section to take advantage of the low cost of mechanical water removal. As a consequence, most of the early work on both mechanisms and performance was restricted to sheets with initial solids levels of 45-50%. More recent work on sheets with initial solids as low as 15% has shown excellent performance and the validity of the original concepts. In the following discussion of mechanisms and performance the earlier data (5,15-18) and the very recent results are integrated into one coherent presentation.

IMPULSE DRYING PERFORMANCE CHARACTERISTICS

Although recent experimentation has concentrated on kraft linerboard past work has evaluated all grades which are major products in the U.S. Included are linerboard, corrugating medium, newsprint, uncoated freesheet writing paper, and coated paper rawstock. Together, these account for two-thirds of total production. All respond well to impulse drying.

Water Removal

The first major effect of impulse drying is rapid water removal. Figure 2 illustrates the sheet final solids content achievable for a few different impulse drying conditions. A lightweight grade, such as coating rawstock at 50 g/m^2, can be dried from 35 to 76% solids in a single, 25 ms nip. This performance could eliminate most of the conventional cylinder drying section of a machine producing a similar grade. Heavier weight materials, such as 125 g/m^2 linerboard, are also effectively dewatered by impulse drying, although the solids after a single nip are not as high.

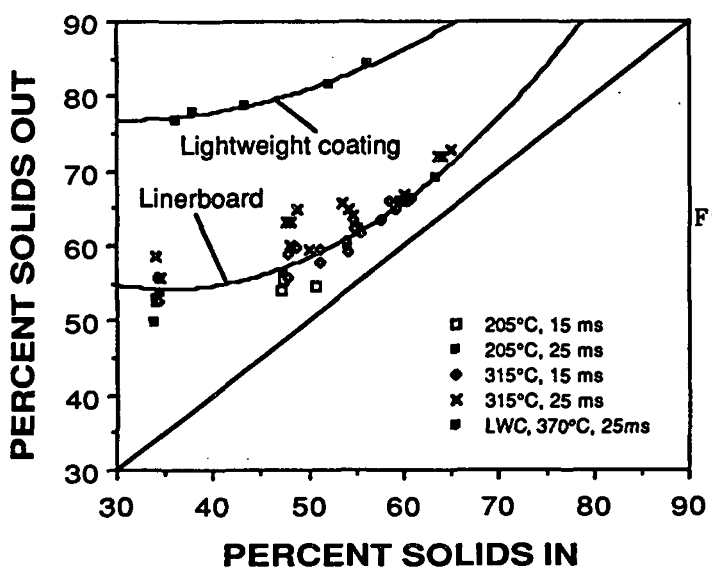

Figure 2. Solids out vs. solids in for linerboard (127 g/m^2) and coating rawstock (50 g/m^2), both preheated to 82°C and impulse dried at 2.8 to 4.8 MPa.

For both grades, dried under given conditions, the final solids content of the sheet is nearly constant for a wide range of solids entering the dryer. This leveling effect may improve both the moisture and properties profiles across the machine.

Higher temperatures and longer nips increase dryness, but applied pressure is of minor importance above about 2.0 MPa peak. Operating at 400°C rather than 200°C increases the final solids of a linerboard sheet by five percentage points for an initial solids of 35%. Preheating the sheet from room temperature to 85°C can improve water removal rates by 30 to 50%, with most of the additional water removed as liquid (15).

Results from experiments on 125 g/m^2 linerboard sheets with solids between 15 and 65% are shown in Fig. 3. For initial solids between 25 and 65%, only about 0.25 kg of vapor is formed for each kilogram of fiber. More steam is formed in the very wet sheets, probably because more liquid water is available at the hot surface. Clearly, in either case, the steam necessary for vapor displacement of liquid is available at some point during the impulse drying event.

Liquid displacement is effective on even relatively dry sheets but increases rapidly with increasing sheet moisture content. For example, at 65% solids, about thirty percent of the total water removed is in the liquid phase, but at 25% this figure increases to over eighty percent. This behavior is expected from a mechanism which depends on a liquid "seal" next to the felt to prevent vapor escape. After impulse drying, about 0.6 kg of water per kilogram of fiber remains over the whole ingoing solids range. This may represent the maximum dewatering achievable with displacement under the given conditions.

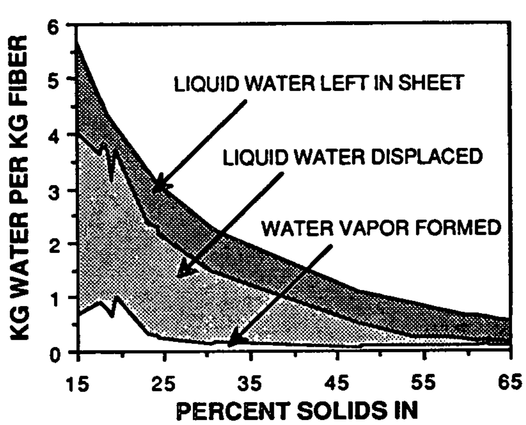

Figure 3. Sheet water balance over a range of initial moisture contents. Linerboard (125 g/m^2), preheated to 82°C, impulse dried at 4.8 MPa, 315°C, for 30 ms.

For very wet sheets, dewatering rates can be as high as 75,000 $kg/hr/m^2$, almost twice those for wet pressing in the same solids range. At 50% initial solids, rates are more typically around 8,000 $kg/hr/m^2$, which is on the order of 500 times that for a cylinder dryer. These very high rates lead, of course, to very small dewatering equipment.

Densification and Physical Properties

Impulse drying increases sheet density and improves the corresponding physical properties. The combination of temperature, pressure, and nip residence time sets up conditions which promote fiber conformability and bond development (8). In general, density varies linearly with solids after impulse drying and is independent of the conditions used to attain the final dryness. For all the grades shown in Fig. 4, the left most point is a control obtained without any impulse drying; the remaining points were obtained by impulse drying under various conditions.

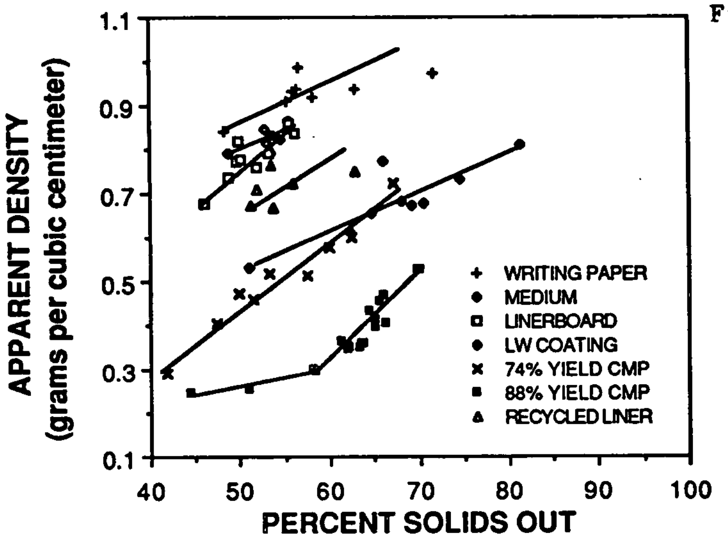

Figure 4. Density *vs*. solids for several grades. Medium, linerboard, recycled liner, and CMP grades at 125 g/m^2; newsprint and lightweight coating rawstock at 50 g/m^2; writing paper at 80 g/m^2. Impulse dried from 50% solids and 26°C at 2.8 and 4.8 MPa, 205 to 370°C, for 15 to 30 ms.

Impulse drying increased the density of all grades tested. However, the density increases were particularly large for high-yield chemimechanical pulps. Strength tends to be a linear function of density, with little dependence on drying conditions, (Fig. 5). Other strength properties, such as burst or compressive strength, exhibit similar behavior. Stretch increases for some grades but remains virtually constant with density for others. For sheets impulse dried on only one side, tear tends to decrease with increasing tensile strength, much as for conventional web consolidation. For sheets impulse dried on two sides, there is some evidence of unusual tear strength preservation with densification.

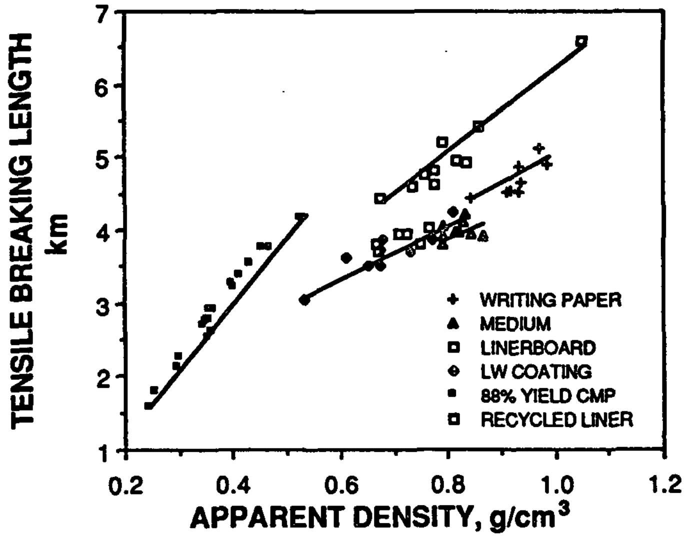

Figure 5. Tensile strength development with densification for grades and conditions in Fig. 4.

The remarkable improvements in the strength of the high-yield furnishes is consistent with work by Dundore (19), who observed increases in both relative bonded area and specific bond strength with even modest amounts of impulse drying on such furnishes. Softening and flow of the lignin and hemicellulose components of the chemimechanical pulp are believed responsible for these results. This is a noteworthy achievement in the very short exposure times of an impulse dryer.

Under many impulse drying conditions, the density profile produced in the sheet is nonuniform. The sheet is very dense near the hot surface, bulky in the middle and moderately dense next to the felt. These J-shaped density profiles, confirmed by photomicrographic evidence and dynamic density measurements, apparently cause some sheet properties to depart from those of a sheet uniformly consolidated to the same average density. For example, lightweight coating rawstock experiences only a four percentage point loss in opacity when density is increased by 1.5 times, probably because most of the light scattering surfaces inside the sheet are relatively unaffected by impulse drying. The unusual tear properties mentioned above may also be related to density profiles.

Energy Efficiency of Impulse Drying

Measurements of water removal in the liquid and vapor phase, as shown in Fig. 3, may be converted into energy demand through a simple but conservative energy balance. Specific energy use declines steadily with decreasing initial solids content to a minimum of about 450 kJ/kg at about 25% solids, (Fig. 6). For still wetter sheets, energy consumption rises. Even for sheets initially at almost 70% solids, energy use is less than 2500 kJ/kg as compared to cylinder dryers which use about 3700-4200 kJ/kg. At 25% initial solids, the advantage of impulse drying is dramatic.

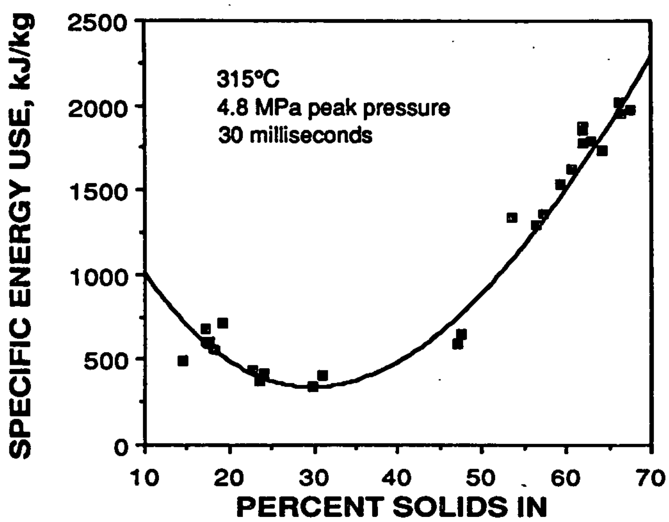

Figure 6. Specific energy use for linerboard (127 g/m^2) preheated to 82°C, impulse dried at 315°C, 4.8 MPa for 30 ms.

Impulse drying is usually carried to solids levels around 65-75%, which leaves appreciable water to be removed in a few cylinder dryers. Figure 7 shows the total energy required to dry to 6% moisture in a combination of an impulse dryer and the necessary cylinder dryers. Use of an impulse dryer could reduce the total energy requirement by one-half for a sheet starting at 35% solids.

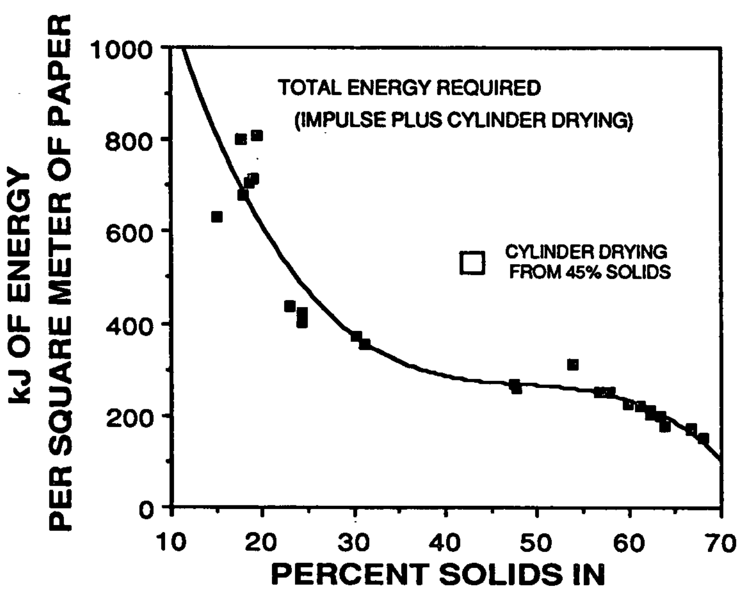

Figure 7. Total energy use for impulse drying (Fig. 6) plus final cylinder drying to 6% moisture for linerboard. Impulse drying efficiency at 70%, cylinder drying energy at 5700 kJ/kg.

These results, plus the water removal data presented earlier, strongly suggest that the third press (35% solids) position may be a very effective site for an impulse dryer. A hypothetical machine, producing 125 g/m^2 linerboard at 650 mpm with 1.5 m diameter cylinder dryers has been analyzed as an example. For this machine, a third press rebuilt as an impulse dryer would reduce the number of cylinder dryers by one-half, the amount of energy by one-third and increase the density by 50%. This could be used to increase pulp yield, decrease refining energy, or reduce pulp costs in other ways. Energy use data for other grades follow similar trends making impulse drying equally attractive for replacing both wet presses and cylinder dryers in those grades, as well. Impulse drying of very wet sheets does not seem to cause any sheet crushing, despite the extremely high water removal rates. This, too, is probably due to the dominance of vapor displacement in impulse drying as opposed to volume reduction in wet pressing. Water handling may be challenging issue, however.

PILOT ROLL IMPULSE DRYER

The platen press described earlier is very useful for laboratory investigation but leaves open many questions about probable industrial practice. Also, the small samples limit physical testing and preclude direct conversion tests. Hence, as a logical next step toward commercialization, a pilot roll impulse dryer has been built. It is intended to address questions about roll geometry, adhesion, delamination, engineering and sheet conversion issues.

A schematic of the pilot roll impulse dryer is shown in Fig. 8. Only one nip is now available; the second will be completed in early 1988. A simple press with two hard rolls was used to avoid the mechanical complexity of a wide nip system. Commercial nip residence times typical of a wide nip press are achieved by running at slow speeds. Electrical infrared heaters heat the top roll and a commercial Nomex wet press felt serves as the water receiver.

Because this dryer system is an Electrically Heated Roll Impulse Dryer, it is referred to by the acronym EHRID.

In general, the test results from EHRID are similar to those from the platen press in all respects and quantitatively equivalent within the limits of experimental error and differences in rewetting. Hence, it can be concluded that the platen press is a good simulator of the roll press (EHRID). Because of this similarity, no specific EHRID data will be presented.

Surface adhesion occurs only for low temperatures, generally below about 175°C. Above this temperature, release from the hot roll is spontaneous, even if the web is not under tension. Since impulse drying is expected to operate above 200°C, adhesion does not appear to be a major issue, at least for the furnishes tested to date.

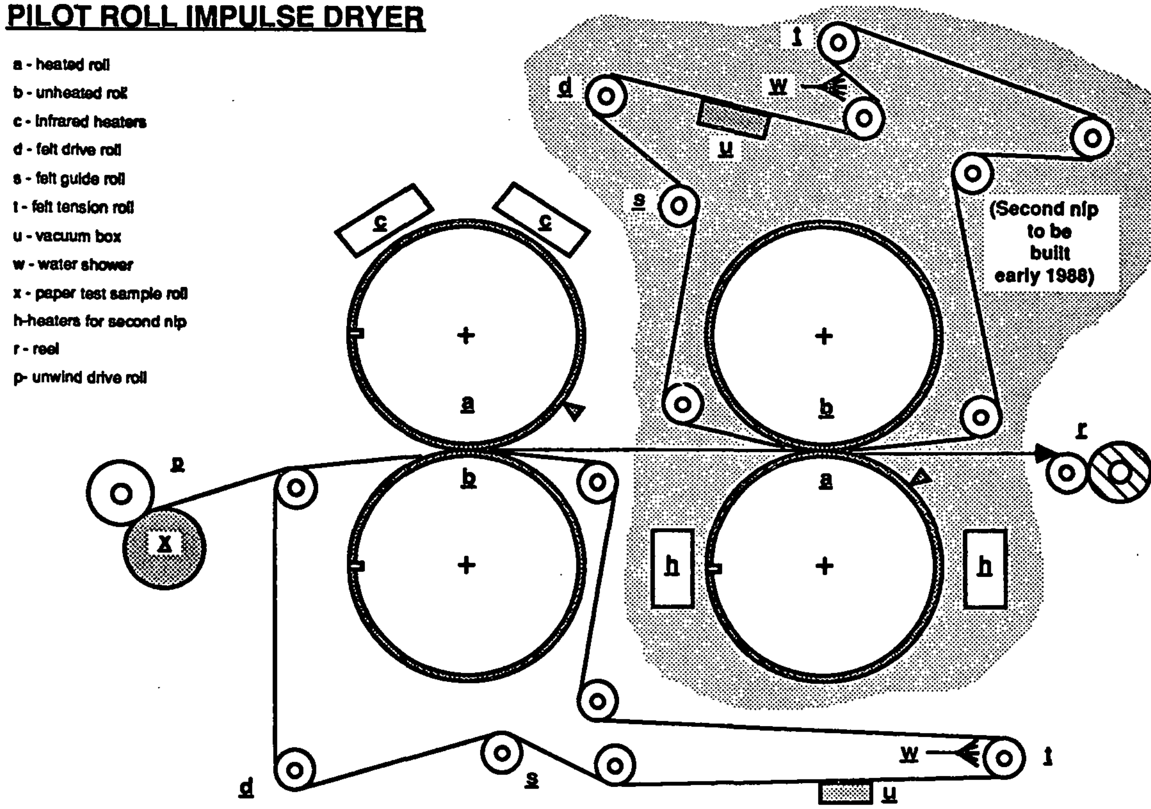

Figure 8. Schematic of the pilot roll impulse dryer.

Delamination is a more serious issue than originally anticipated, especially for heavy or highly refined sheets. Early work was devoted mostly to lighter weights and low levels of refining which obscured the seriousness of the delamination issue. Delamination occurs when hot water remaining in the sheet flashes, sometimes violently, as the sheet leaves the nip. The resulting vapor pressure may exceed the intrinsic sheet strength, leading to rupture. Delamination may restrict the allowable operating window for a given grade. To widen this window, or remove the restrictions altogether, it is necessary to limit the heat addition to the sheet. There are several ways for doing this, but discussion of these will be reserved for a later paper.

Previous work on the platen press has shown improvements in smoothness, ink holdout, water absorbency, and other properties important to conversion. However, the small samples precluded any direct evaluation of the converting performance of impulse dried sheets. One of the primary purposes of EHRID was to provide large paper samples for this purpose. This work has been initiated, and many samples are now in various stages of evaluation. Only a few tests have actually been completed. As an example, preliminary results on the bonding performance of linerboard from a dynamically simulated double backing test are very encouraging. Bonding of a single faced web to either side of the impulse dried liner - hot surface or felt side - was consistently better than for an identical sheet processed conventionally.

CONCLUSIONS

The major new conclusions from recent efforts are as follows:

1. The impulse drying mechanisms for wet sheets are the same as those for well-pressed sheets.
2. The energy use efficiency and extraordinary water removal performance of impulse drying of wet sheets may allow portions of both the press and dryer sections to be replaced.
3. Impulse drying performance is similar on the roll press and on the platen press.
4. Linerboard glueability is improved by impulse drying.
5. Delamination is a much more important problem than originally anticipated.

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